Atomic and radiative processes in high-Z plasmas and their applications

Yang Li[1], Xiaokai Xu[1], Ming Dong[1], Bowen Li[1], Ximeng Chen[1], Takeshi Higashiguchi [2], Hayato Ohashi [3], Chihiro Suzuki[4] , Emma Sokell[5], Pdaraig Dunne[5] and Gerry O'Sullivan[5]

[1]School of Nuclear Science and Technology, Lanzhou University, Lanzhou, 730070, China
[2] Utsunomiya University, Utsunomiya, Tochigi 321-8585, Japan
[3]University of Toyama, Toyama, Toyama 930-8555, Japan
[4]National Institute for Fusion Science, Toki, Gifu 509-5292, Japan
[5]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland

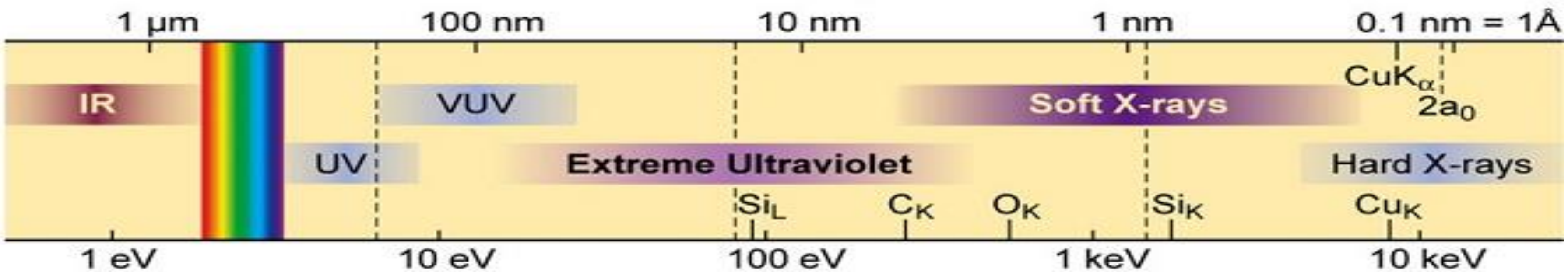
Outline

- ❖High-Z plasma spectra
- ❖LPP spectra Hf and Ta
- ❖Conclusion

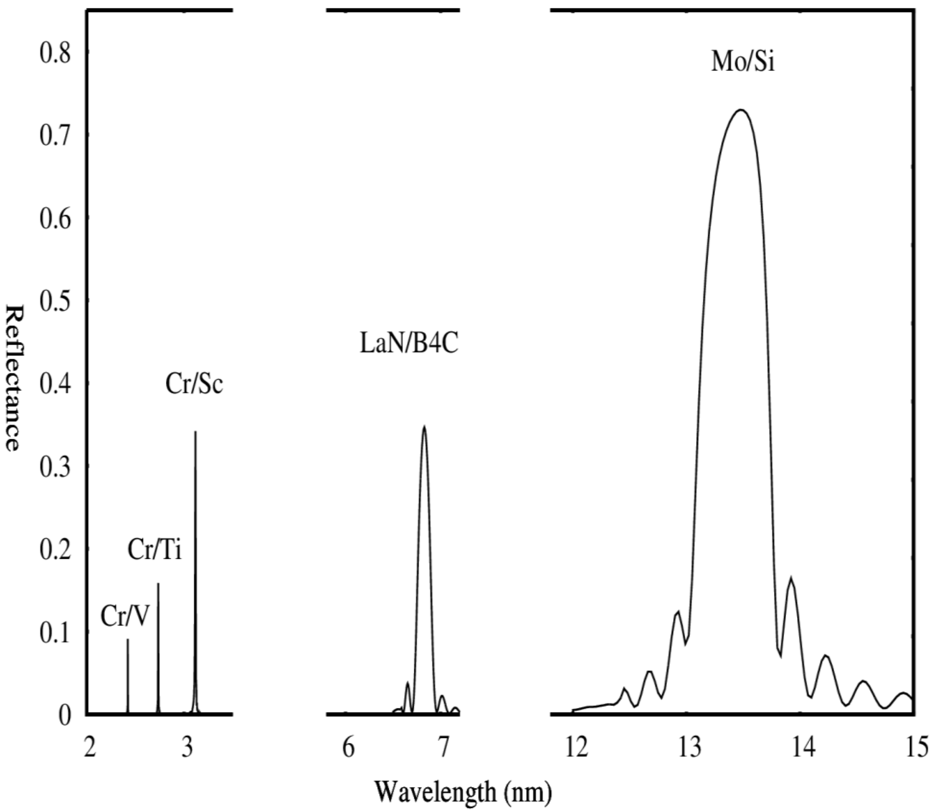
Outline

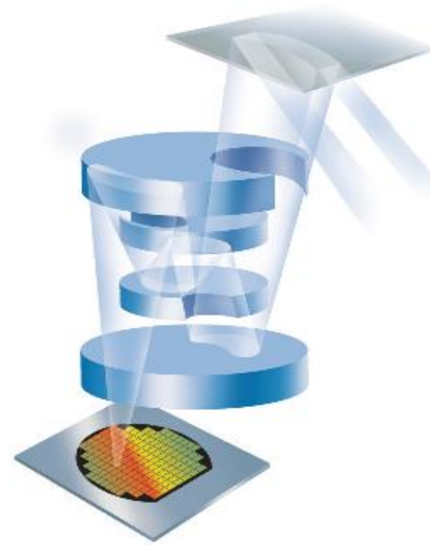
- ❖High-Z plasma spectra
- ❖LPP spectra Hf and Ta
- ❖Conclusion

Plasma sources below 10 nm

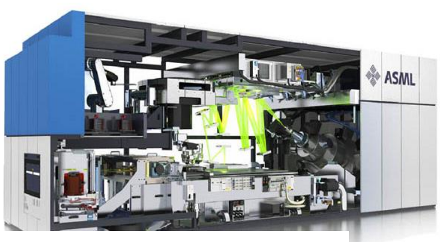


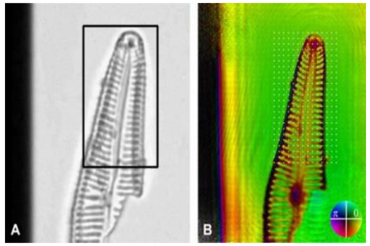
$$\Delta x = \frac{k\lambda}{NA}$$

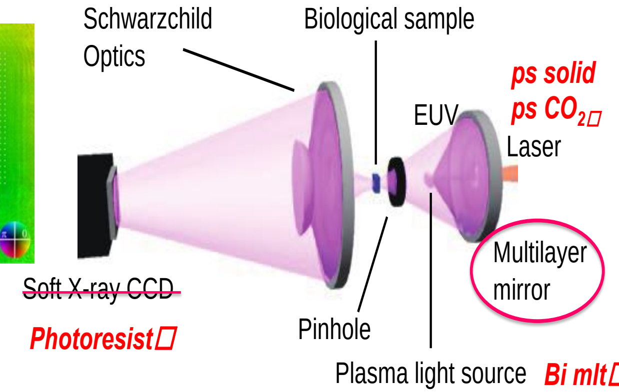




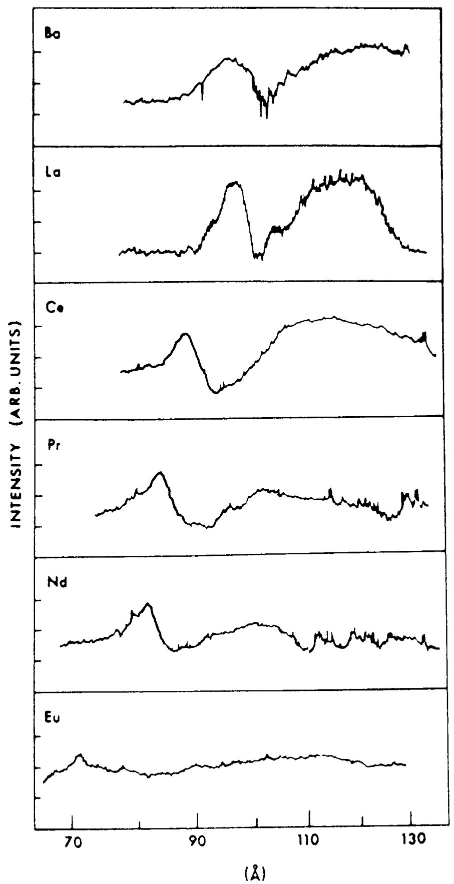
$$CE = \frac{Inband\ Energy}{Incident\ Laser\ Energy} \times 100.$$



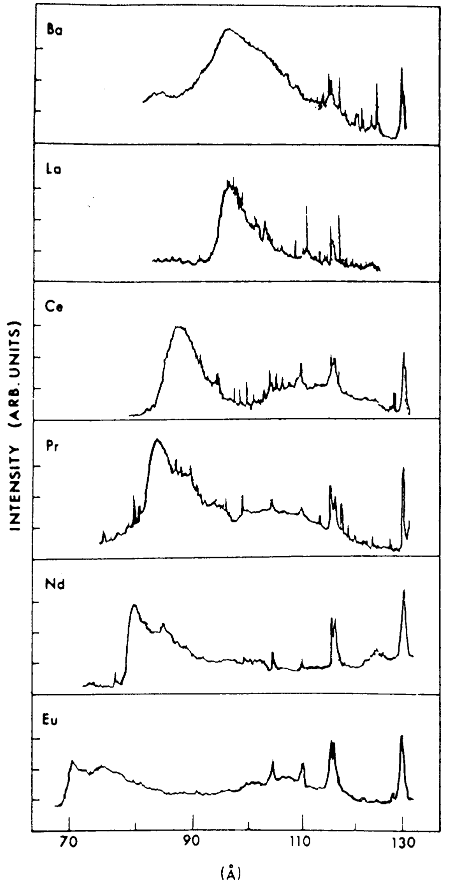




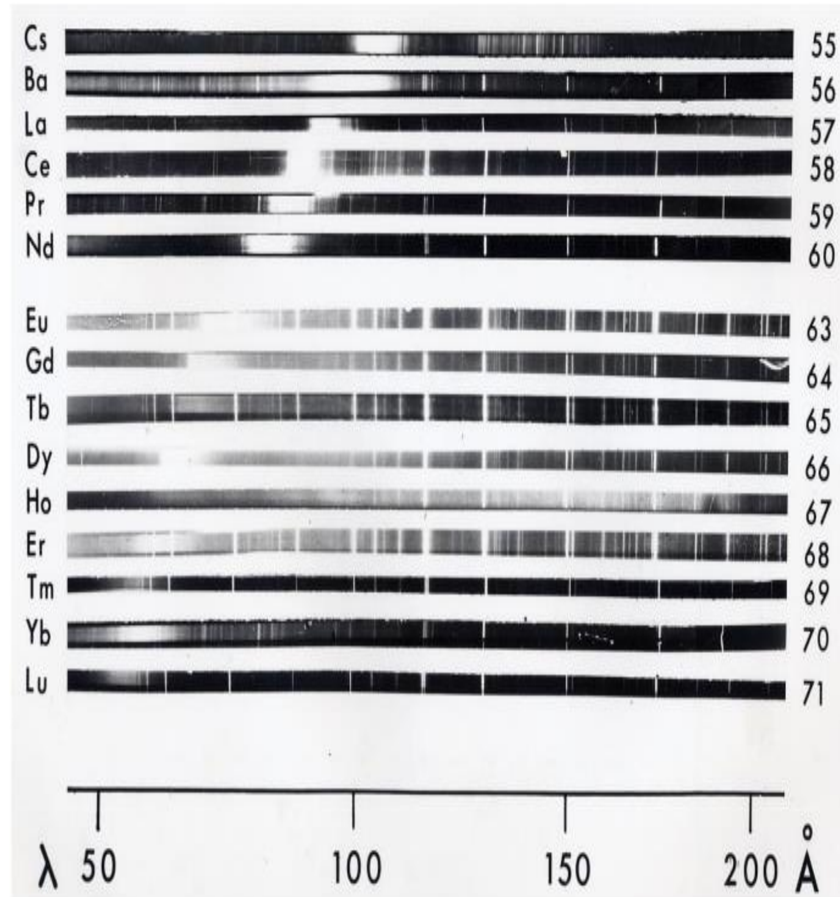
High-Z plasma spectra



Metal target



Salt target

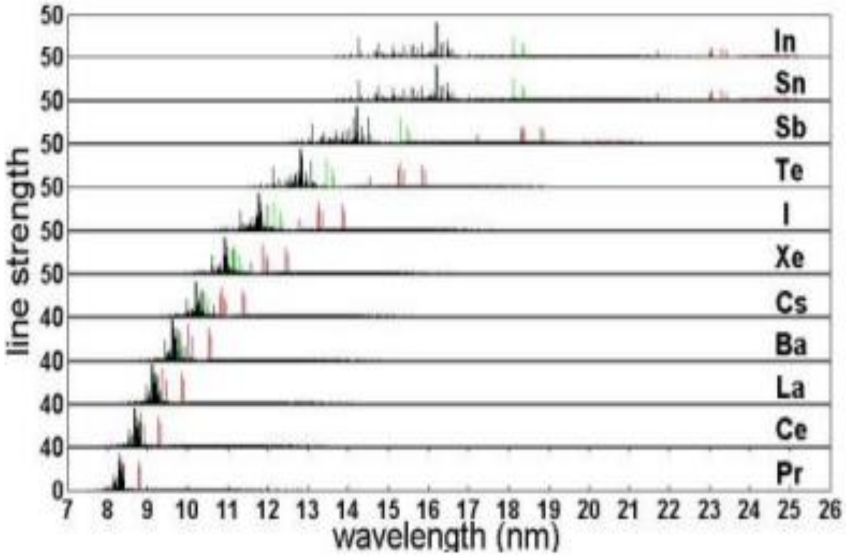


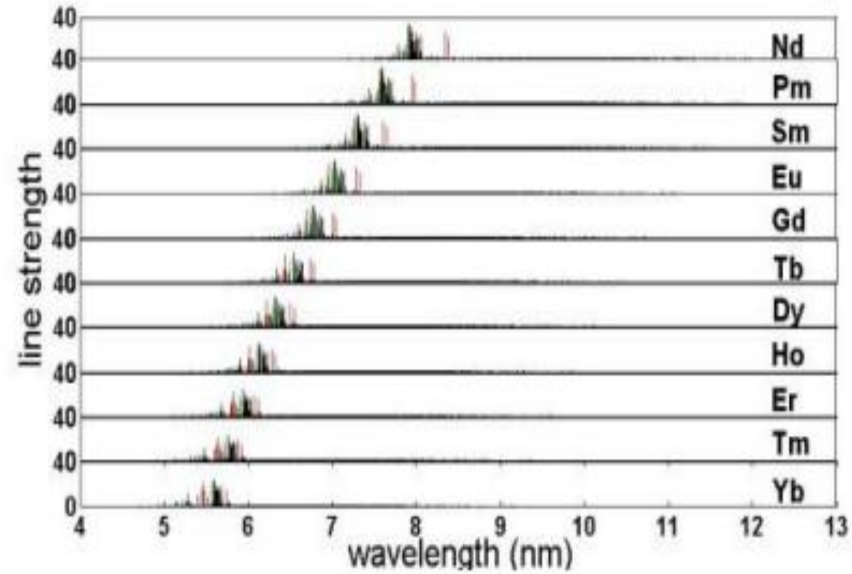
$\lambda \propto$ **1/Z²**

Strongest features due to $4p^64d^n$ - $4p^54d^{n+1}$+$4d^{n-1}4f$ transitions that form a unresovled transition array (UTA).

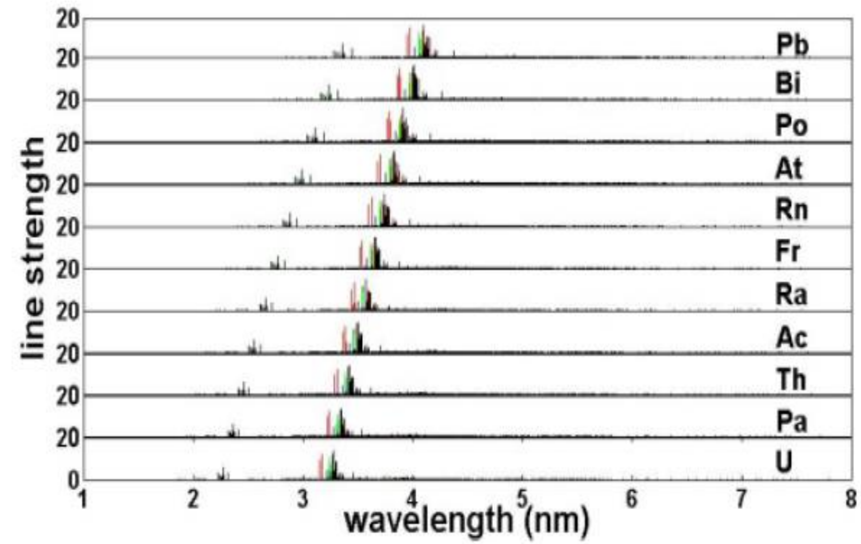
G. O'Sullivan. and P. K. Carroll, J. Opt. Soc. Am, 71 (1981) 227

Variation of UTA vs Z



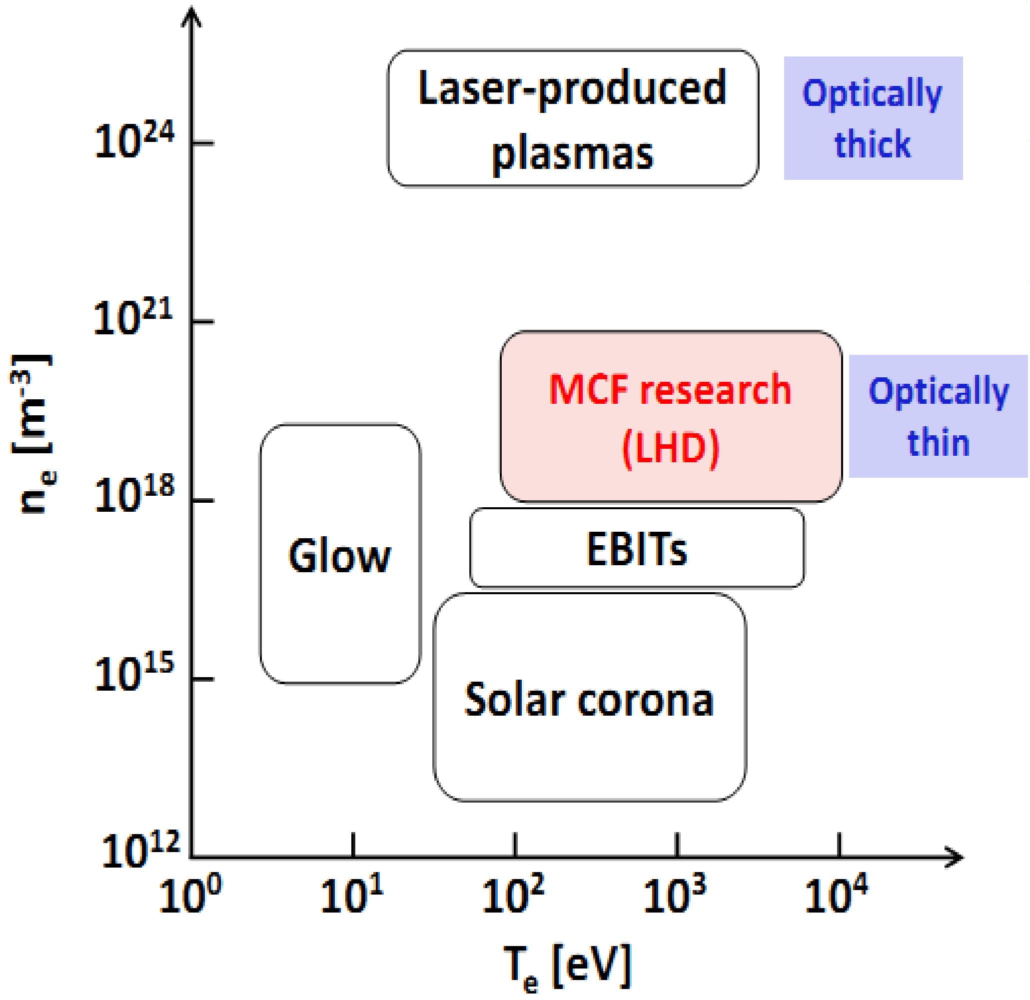


Calculated positions of the strongest n = 4 – n = 4 transitions for four stages of each element corresponding to Ru-like (red) , Rh-like (blue), Pd-like (green) and Ag-like (black) ions.



Bowen Li, et al. Proc. SPIE **8139**, 81390P (2011).

Experiment



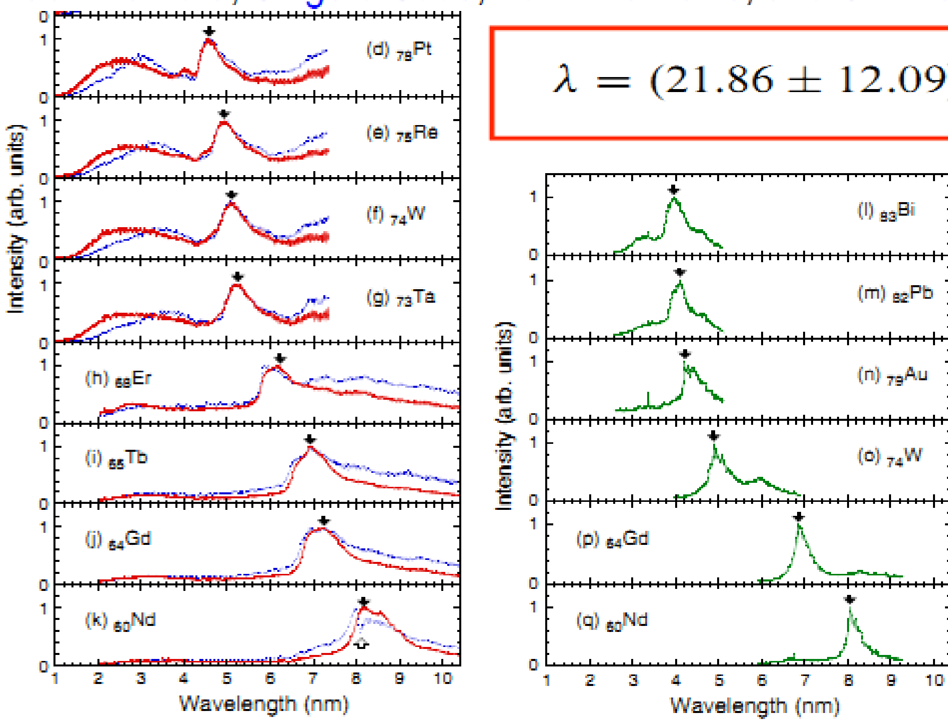
After Chihiro Suzuki

- **Parameter**
  emission/absorption spectra, T_e, N_e, abundance
- **Optimum conditions**
  laser wavelength, T_e, N_e, pulse duration, opacity
- **Benchmark**

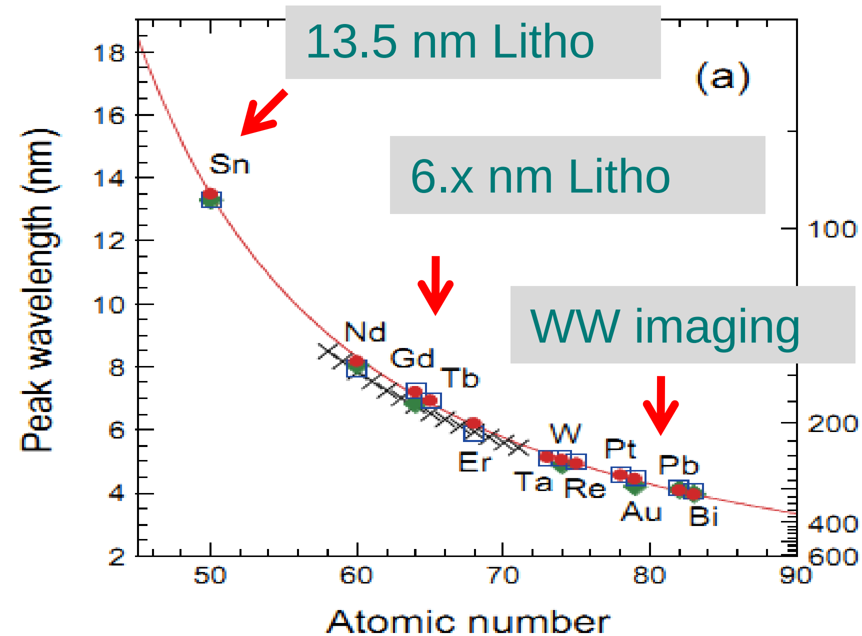
AIP | Applied Physics Letters

Quasi-Moseley's law for strong narrow bandwidth soft x-ray sources containing higher charge-state ions

Hayato Ohashi, Takeshi Higashiguchi, Yuhei Suzuki, Goki Arai, Yukitoshi Otani, Toyohiko Yatagai, Bowen Li, Padraig Dunne, Gerry O'Sullivan, Weihua Jiang, Akira Endo, Hiroyuki A. Sakaue, Daiji Kato, Izumi Murakami, Naoki Tamura, Shigeru Sudo, Fumihiro Koike, and Chihiro Suzuki



$$\lambda = (21.86 \pm 12.09) \times \frac{1}{R_\infty} \times [Z - (23.23 \pm 2.87)]^{-(1.52 \pm 0.12)}$$

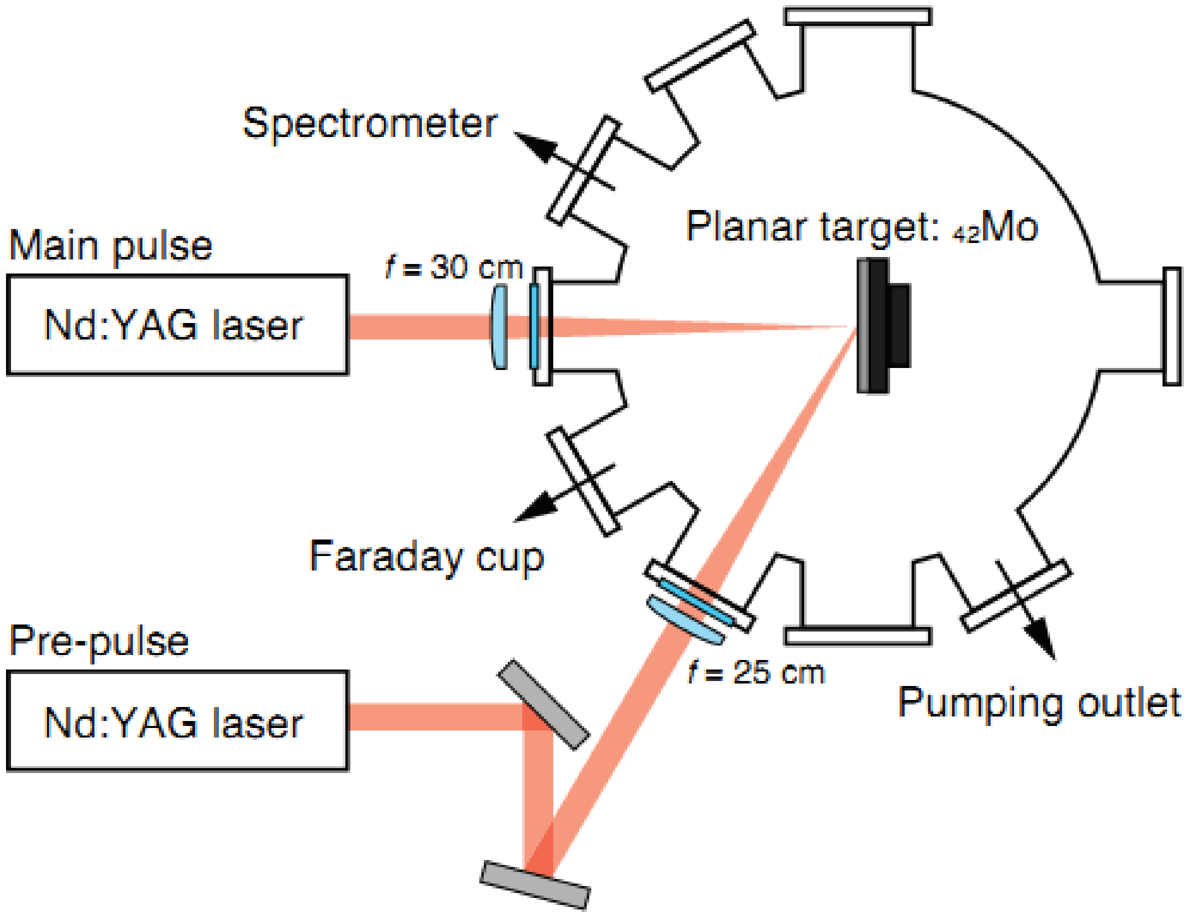


Applied Physics Letters **104**, 234107 (2014)

Outline

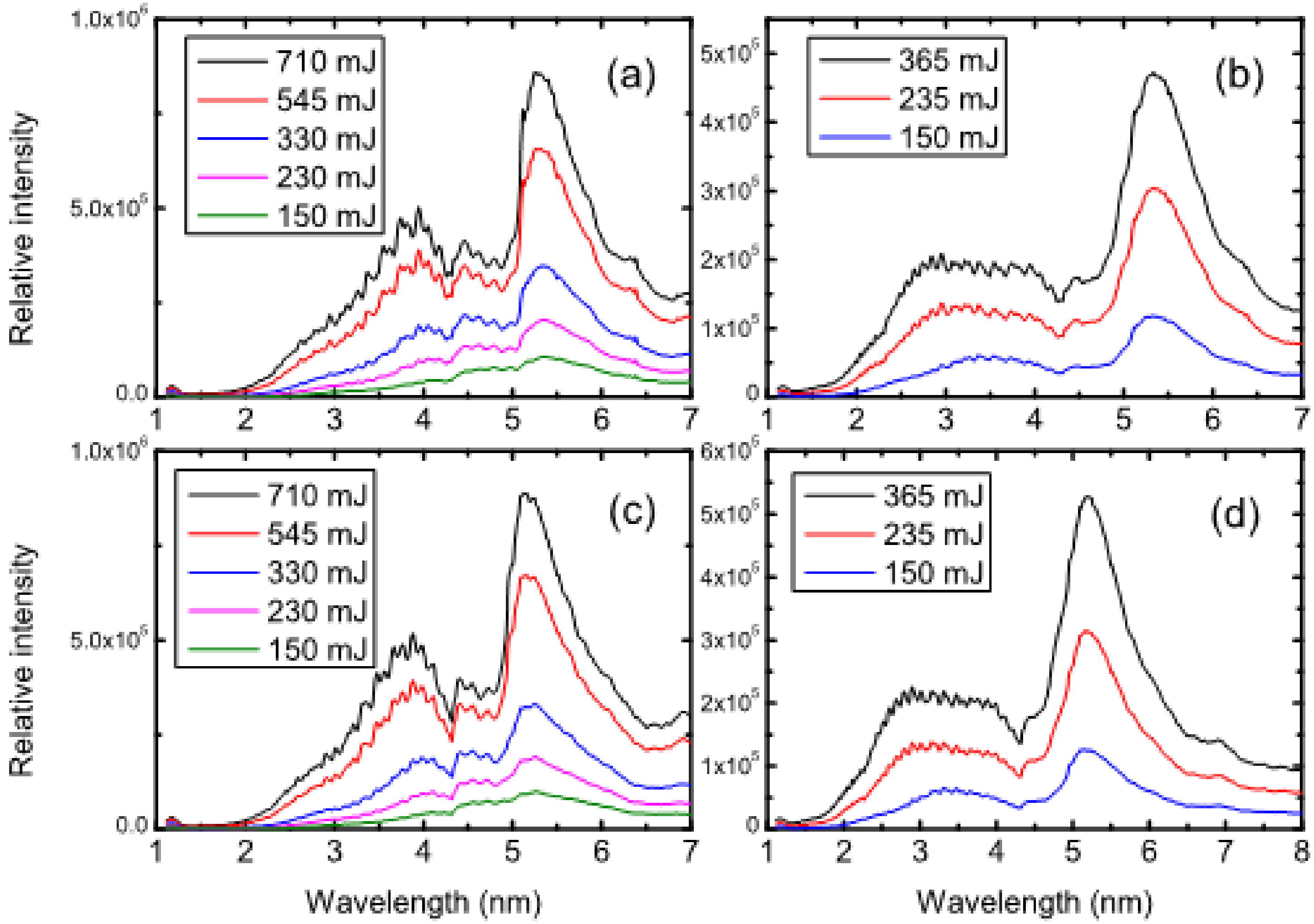
- ❖High-Z plasma spectra
- ❖**LPP spectra Hf and Ta**
- ❖Conclusion

Experimental setup

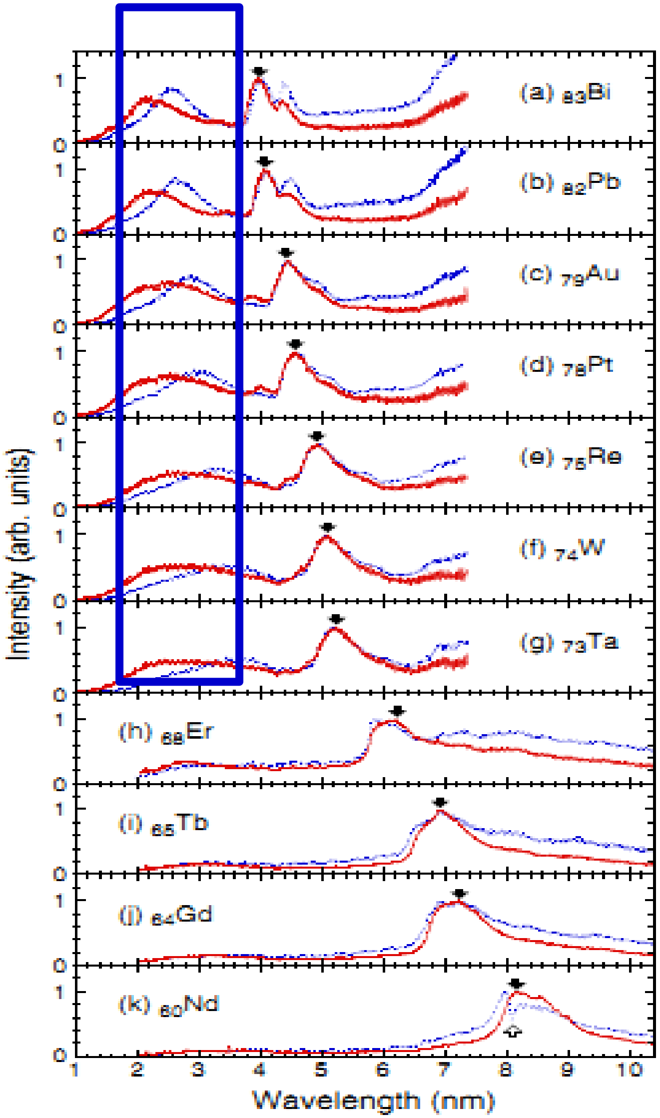


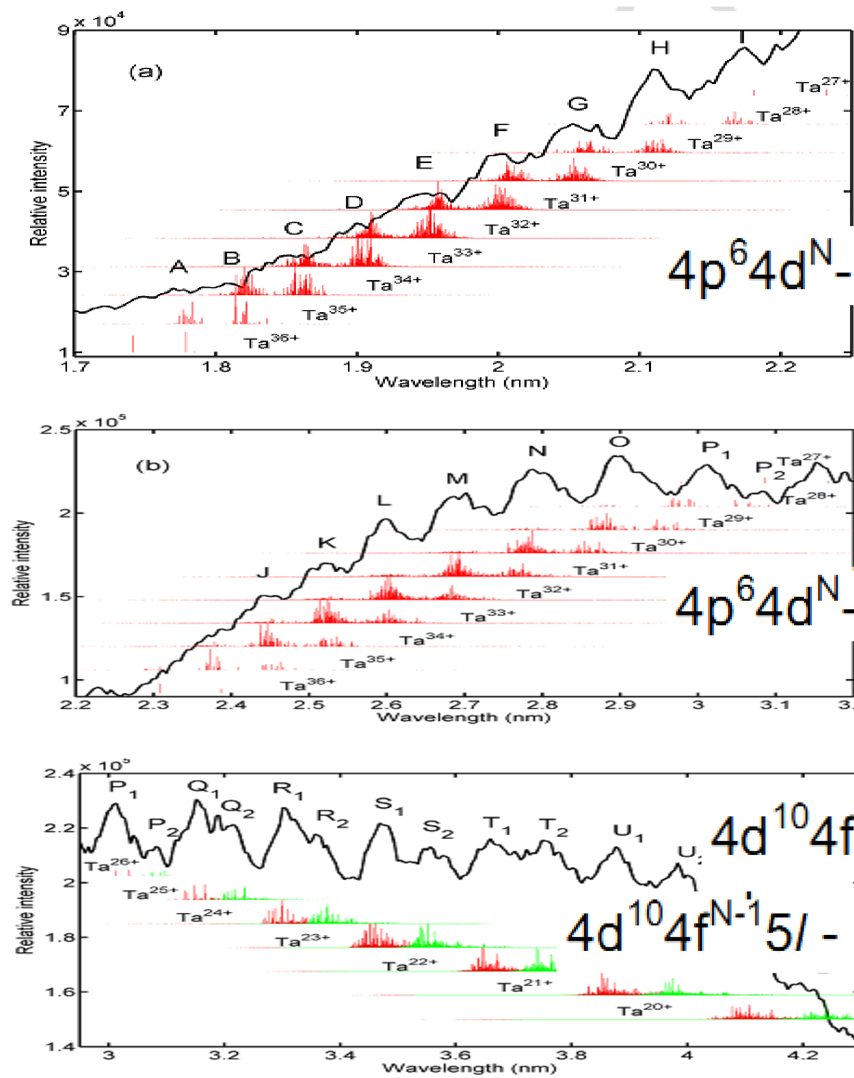
R. Lokasani, et al., Appl. Phys. Lett. 109 194103 (2017)

LPPs spectra of Hf and Ta



Δn = 1 transitions





$4p^6 4d^N - 4p^6 4d^{N-1} 5p$

$4p^6 4d^N - 4p^6 4d^{N-1} 5f$

$4d^{10} 4f^N - 4d^9 4f^{N-1} 5g$

$4d^{10} 4f^{N-1} 5l - 4d^9 4f^{N-2} 5l/5g$

Au, W, Re, Pt, Bi, Hf and Ta bear a striking similarity feature

Effects of Dual laser

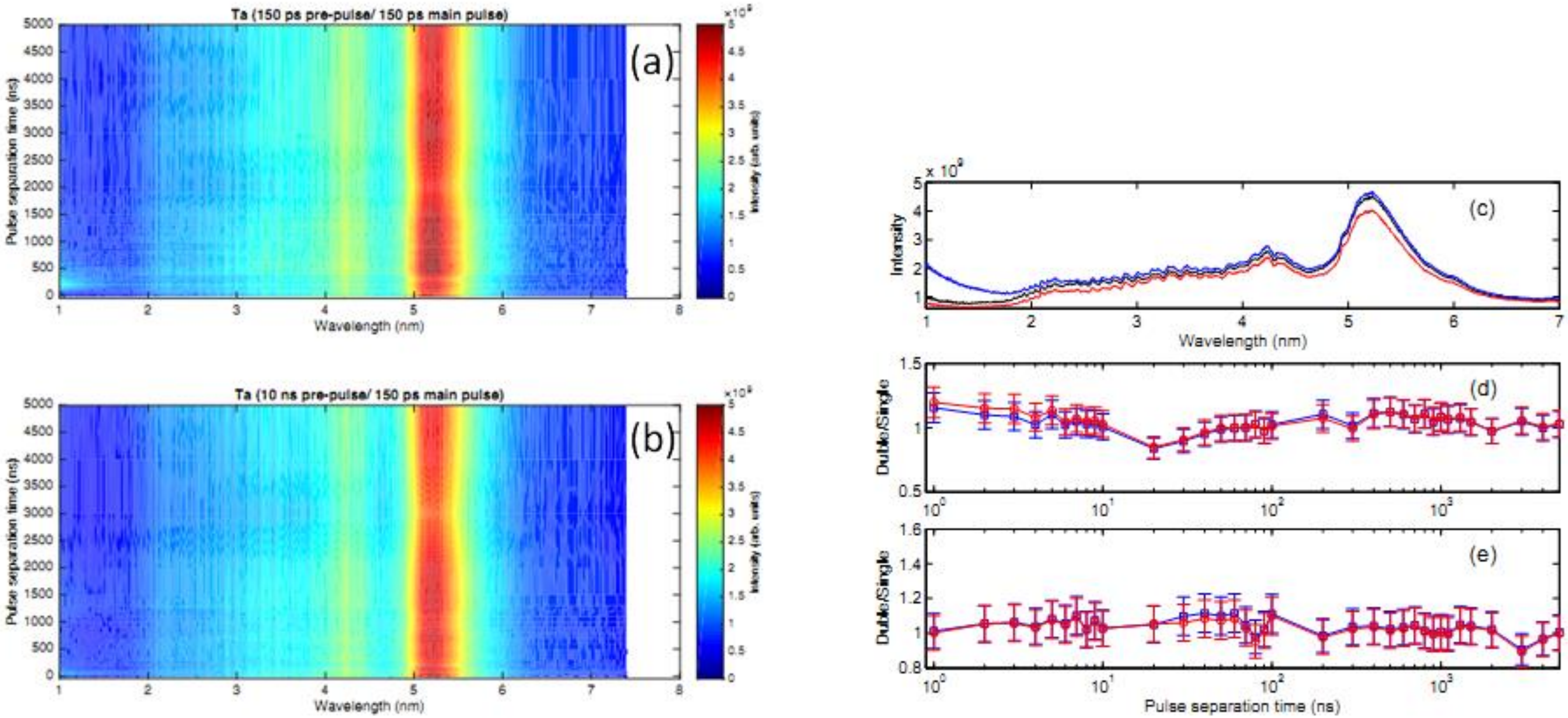


Fig. 7. Pulse separation time dependence of the SXR emission from a dual LPP Ta plasma with pulse durations for (a)150 ps pre-pulses; (b) 10 ns pre-pulses; (c) Time integrated spectra without pre-pulse (black line) and with pre-pulses at different pulse separation times of 60 ns (red line) and 200 ns (blue line). The duration of the pre-pulse was 150 ps. Ratio of integrated emission intensities in the 1-7 nm (black)and water window region (red) obtained by dual laser and single laser irradiation as a function of pulse sepration times (d)pre-pulse duration was 150 ps (e) pre-pulse duration was 10 ns.

Conclusion

1. Quasi-Moseley's law of $\Delta n=0$ 4d-4f transitions for higher charge-state ions.
2. Soft X-ray (SXR) spectra from Hf and Ta LPPs were recorded in the 1-7 nm region, some prominent features in the spectra are identified.
3. An enhancement of emission can be achieved using dual laser irradiation.

Thank you for your attention!

libw@lzu.edu.cn